Available online at www.sciencedirect.com
ScienceDirect
Journal of Bionic Engineering 5 (2008) 67−73

Electronic Nose with an Air Sensor Matrix for Detecting Beef Freshness

Zhe Zhang[1], Jin Tong[1], Dong-hui Chen[1], Yu-bin Lan[2]

1. *Key Laboratory of Terrain-Machine Bionics Engineering* (*Ministry of Education*, *China*), *Jilin University*, *Changchun* 130022, *P. R. China*
2. *Aerial Application Technology*, *USDA-ARS-SPARC-APMRU*, *College Station*, *TX* 77845, *USA*

Abstract

China is one of the largest meat producing countries in the world. With the growing concern for food safety more attention has been paid to meat quality. The application of conventional test methods for meat quality is limited by many factors, and subjectiveness, such as longer time to prepare samples and to test. A sensor matrix was constructed with several separate air sensors, and tests were conducted to detect the freshness of the beef. The results show that the air sensors TGS2610, TGS2600, TGS2611, TGS2620 and TGS2602 made by Tianjin Figaro Electronic Co, Ltd could be used to determine the degree of freshness but TGS2442 is not suitable. This study provides a foundation for designing and making an economical and practical detector for beef freshness.

Keywords: gas sensitive sensor matrix, degree of beef freshness, electronic nose

1 Introduction

China is one of the largest meat producing countries. In 2003 the total meat production of China was 100 million tons, which accounts for one third of the total world production with a total of 300 million tons[1]. The chemical compounds of meat are very complex. There are about 10%−30% fatty, 10%−20% protein and 1%−5% sugar in meat[2]. The putrifaction speed of meat is quick because microorganisms can easily develop in it. There have been many serious accidents in food safety since 1990's. For example, meat was infected with *Listeria* at the beginning of 2001 in France, and chloromycetin was detected in the products of shell fish exported to Europe, American and Canada from Asia in 2006[3]. There are up to 81 million patients on average suffering from food poisoning in developed countries every year. Therefore, great attention has been paid to food safety around the world.

According to the present quality criterion of beef, mutton and rabbit meat, there are two kinds of method to evaluate the quality of beef: sensory and chemical[4]. Sensory evaluation is a subjective method whose results depend upon the natural skills of operators and, as a result, there are frequent errors. There are more chemical methods for inspecting meat quality, for example, Total Volatile Basic Nitrogen (TVBN), pH, Triphenyltetrazolium chloride (TTC), and test paper. There are shortcomings, such as more procedures, longer time, higher expense and not enough precision in the chemical methods[5]. Gas measurement is one of the chemical methods for quality evaluation of meat. The odor is detected when the olfactory cell in the nose is excited by a volatile gas. Gas chromatography is commonly used for measuring gas contents and it can be used to measure many chemical compounds compared with standard chemicals. Therefore, an objective, economic and high efficient method is needed to evaluate the meat quality.

Food odor is a combination of many chemical substances. Odor gives food some unique quality and characteristics. Reliable measurement, identification of optimal flavor and constant taste characteristics of food are crucial in food development. Conventionally, it was difficult to correlate with sensory information although

Corresponding author: Jin Tong
E-mail: jtong@jlu.edu.cn

some analytical techniques were used.

As a new physical method for measuring smell, the electronic nose technology has been used. The electronic nose is defined by North Atlantic Treaty Organization (NATO) in an international conference on the treatment of sensor signals in 1989[6]. Measurement using an electronic nose was compared with other measurement methods based on the objective, repeatable, accurate and economic standards. It was found that the electronic nose is simple, quick, and makes real-time measurement. The structure of an electronic nose is similar to the human sense of smell, learning from the functions of analyzing, recognizing and identifying volatile chemicals to higher precision. The electronic nose technology is based on the absorption and desorption of volatile chemicals onto a matrix of sensors. The sensor elements detect the change of electrical resistance when they contact gas with the varied odors and aromas[7]. Electronic nose technology is especially useful as a rapid measurement method for food which has been stored for a long time and gases may present risk to the human olfactory cells. At present, the electronic nose is mainly used to classify the quality of stored grain, analyze water and wastewater, monitor roasting process, detect and diagnose pulmonary infections (e.g., pneumonia) and ulcers through breath tests, test freshness of fish and fruit, control the manufacture of cheese, sausage, beer, and bread, detect bacterial growth in meat and vegetables[8–12].

The electronic nose was also used to measure the freshness of beef. Teng *et al.*[13] examined the freshness of beef using a gas sensitive sensor matrix made in Germany, where the number and type of sensors are fixed. Blixt and Borch[14] examined the spoilage of vacuum-packed beef using an electronic nose containing a sensory matrix composed of 10 metal oxide semiconductor field-effect transistors, four Tagushi type sensors and one CO_2-sensitive sensor. Six sensors were used at least, however, these sensors were not constructed into an array.

There are various commercial electronic noses. An integrated sensor matrix is used in most of them, suggesting that one electronic nose is designed for a specific purpose. The purpose of this study is to use the gas sensors to construct a sensor matrix for determining freshness of beef.

2 Experiments

2.1 Working principles and structure of measuring head

2.1.1 Working principles

The design of an electronic nose includes the design of a matrix of chemical sensors, for example, gas sensors, and development of a pattern-recognition algorithm. The sensor matrix sniffs the vapor from a sample and provides a set of measurements; the pattern-recognizer compares the pattern of the measurements with the stored patterns of known materials. Gas sensors tend to have very broad selectivity, responding to many different substances. This, in fact, is a disadvantage in most applications, but it is a definite advantage in the electronic nose. Each sensor in a matrix may respond to a given chemical and these responses will be different[5]. Fig. 1 shows the sketch of electronic nose system developed by us. Several sensors are arranged in a cabin and constructed into a sensor matrix. The flavor is detected by the sensor matrix and electric signals are generated. The signals are filtered and amplified by an Adjustment Circuit Board (ACB), and converted to digital signals by A/D transfer card and the digital signals are analyzed by a computer.

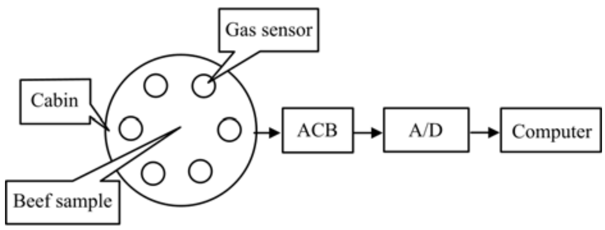

Fig. 1 Electronic nose system.

There are many types of gas sensors with different working principles and behaviors. The gas sensors chosen in this study are manufactured by Tianjin Figaro Electronic Co, Ltd. These sensors are made from semiconductor of metal oxide and have such characters as low cost, long life, high sensitivity and simple circuit requirement. Models 2600, 2602, 2610, 2611, 2620, 2442 were selected for this study to see if they are suitable for various gases volatilized from beef. A sensor matrix can decrease the error inherent in a single sensor. Table 1 lists the usages of six sensors recommended by the manufacturer.

Table 1 Recommended usages of sensors

Models	Usage	Main object of measurement	Typical examples
TGS 2610	Burnable gas check	Propane, isobutane	Leakage alarm of LPG
TGS 2600	Air quality control	Smoke, alcohol	Air quality controller
TGS 2611	Burnable gas check	Methane, natural gas	Leakage of natural gas
TGS 2620	Organic solvent check	Alcohol, organic solvent	Organic solvent checker
TGS 2602	Air quality control	Alcohol, air ammonia	Air quality controller
TGS 2442	Toxic gas check	CO	Alarm of CO

Model CMB5464D of ACB used for this study was made in Beijing Kangtuo Industrial Computer Ltd, which can adjust eight simulation signals. The signals are amplified and fed to a 2nd order source filter for analysis. Model IPC5448 of A/D transfer card used for the tests is produced by Beijing Kangtuo Industrial Computer Ltd. It converts analog signals into digital signals. It has a transfer card of 12 bits, with high precision, high speed, large measurement range and powerful anti-interference. The analysis procedure was written and signals were recorded, stored and displayed in Visual C++ program with a computer.

2.1.2 The measuring head of electronic nose

Fig. 2 shows the measuring head of the electronic nose developed and Fig. 3 is a diagram of its structure. The sensors are arranged on the bottom of the cabin. A stainless steel grid is fixed at the middle of the cabin to avoid the sensors touching the beef sample and to ensure a suitable distance between the sensors and beef sample since the results will be affected by the arrangement of the sensors and the distance between the sensors and the beef sample. The measurement is started after putting the beef sample onto the stainless steel grid.

Fig. 2 Photograph of the measuring head of electronic nose developed.

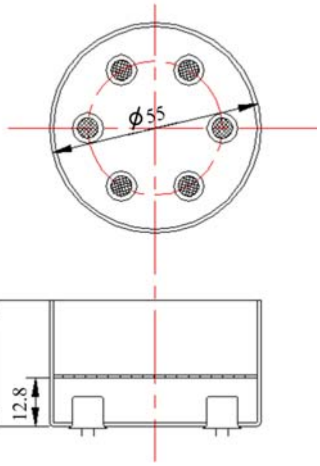

Fig. 3 The schematic diagram of the measuring head of the electronic nose developed.

2.2 Experimental methods

2.2.1 Preparation of beef sample

The beef used for tests was provided by Changchun Haoyue Group. The beef was cut into pieces with about 45 mm in diameter and 4 mm thick. These pieces were divided into three groups in order to repeat the measurement three times for one identical condition. The beef samples were put into an incubator to simulate the change of beef stored under the room environment. The beef samples were stored for 0, 1, 2, 3, 4, 5 and 6 days, respectively, at temperature of 20 ˚C and relative humidity of 60%.

2.2.2 Design of circuit

Fig. 4 shows the principle circuit of the electronic nose, where, V_c is the working voltage of the sensor, R_s is the resistance of the sensor, R_L is the loading resistance, R_s and R_L are connected in series, V_{AL} is the output signal voltage of the sensor. According to the specification of the sensor, the initial value of V_{AL} is about 0.1 V, and the maximum value is 0.9 V. The output of the sensor is linear within this voltage range (0.1 V~0.9 V). V_{AL} can be changed by adjustment of R_L. The sensor was calibrated with the beef samples. The initial value of V_{AL} was the output value of the beef sample stored for 0 day and the maximum value of V_{AL} was the output value of the beef sample stored for six days.

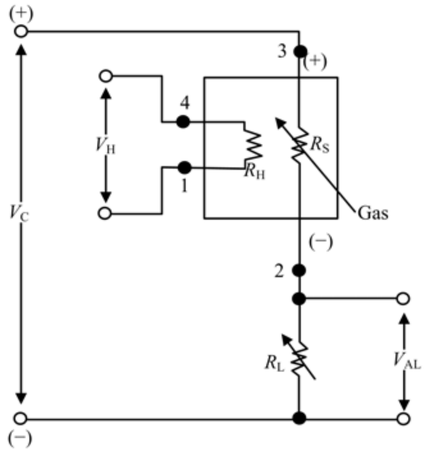

Fig. 4 Principle diagram of the circuit for sensor.

The zero and degree of amplification of ACB were adjusted with the zero resistance and the amplification adjustment resistance, respectively. The purpose of zero adjustment was to calibrate the initial state of amplifier. The amplification was adjusted according to the changeable range of V_{AL}. The output of amplifier should be maximum at the maximum value of V_{AL} to ensure the linear response of the amplifier.

The zero and amplification of A/D transfer card should be adjusted before measurement. The adjustment procedure was: zero adjustment, amplification adjustment. Zero was changed when the amplification was changed. In order to adjust zero, the above steps were repeated until the full scale of A/D card was corresponding to the maximum output signal of ACB.

2.2.3 Experimental procedure

In order to simulate natural conditions better, the beef was not stored in any special gas but in the laboratory air surrounding, the same air was used with the electronic nose.

The odor and color of beef samples were first evaluated by sensory evaluation and the results were recorded. Then, the measurement was conducted by the sensors and the results were also recorded. The results of the sensor measurement were therefore confirmed by the sensory evaluation. The measurement was done in the laboratory conditions without any special requirements considering the application at shopping center, restaurant, storage room and others.

According to the sensor specification, the cabin was pre-heated for 10 min. This was found to be insufficient, so we used a pre-heat time of 1.5 h, which produced a stable initial value. The output voltage of the sensor was recorded with a voltage meter. The beef sample was put into the cabin and, when the voltage was steady, the reading was recorded. The measuring time was 5 min to 10 min. Next measurement was started when the initial value was steady.

3 Results and discussion

Fig. 5 shows the test results of the typical response of the six sensors for stored beef. The output voltages of all sensors except TGS2442 increased at the beginning and then decreased to stable values.

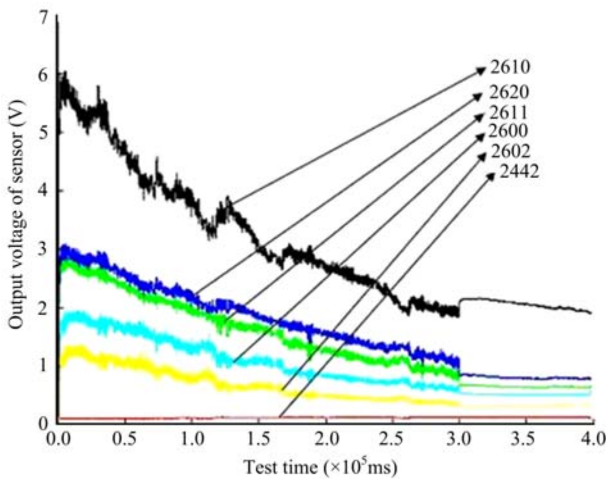

Fig. 5 Test results of the typical responses by the six sensors for stored beef.

Table 2 lists the average values of the voltage readings from the six sensors used for tests. Each datum is the average of three measurements under identical conditions. Fig. 6 shows the output curve of the sensors corresponding to Table 2. Table 3 lists the results of the sensory evaluation.

Table 2 Output voltage of the sensors

Stored time (days)	Gas sensors					
	TGS2610	TGS2600	TGS2611	TGS2620	TGS2602	TGS2442
0	0.183,333	0.246,667	0.256,667	0.306,667	0.116,667	0.036,667
1	0.206,667	0.420,000	0.306,667	0.410,000	0.136,667	0.033,333
2	0.260,000	0.616,667	0.316,667	0.566,667	0.253,333	0.036,667
3	0.326,667	0.703,333	0.523,333	0.763,333	0.630,000	0.033,333
4	0.573,333	0.843,333	0.656,667	0.816,667	0.726,667	0.033,333
5	0.826,667	1.003,333	0.956,667	0.946,667	0.936,667	0.040,000
6	0.843,333	1.023,333	1.036,667	1.046,667	1.013,333	0.036,667

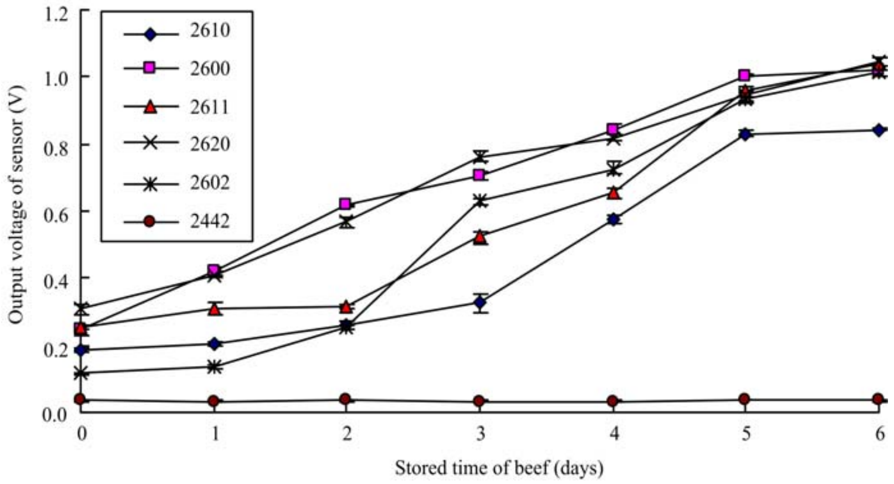

Fig. 6 Output voltage curve of the sensors.

Table 3 The results of sensory evaluation

Stored time (days)	Color	Odor
0	Fresh red	No peculiar smell
1	Deep red	No peculiar swell
2	Dark red	No peculiar smell
3	Black red	Light peculiar smell
4	Black	Smelly
5	Deep black	Stink
6	Dark black	Foul

Different sensors can respond to different gases (Table 1), suggesting each sensor has a different output voltages for each gas. The odor of beef results from a mixture of gas compounds. Thus, each sensor has a different output voltages for beef. This conclusion is confirmed by the results illustrated in Table 2. We utilized the different sensors to construct a sensor matrix. The odor was measured by several sensors simultaneously and the data were processed. High measuring precision and repeatability could be achieved. Except TGS2442, the output voltages of the sensors increased with the stored time of the beef sample.

It is found in Fig. 6 that the output voltage curve of TGS2442 is close to a flat straight-line with the stored time, suggesting that this sensor can not be used to measure beef freshness. As a result, this sensor should not be used in the sensory matrix of the electronic nose for beef freshness examination, suggesting that there are only five sensors in the sensor matrix which should be used. The outputs of TGS2600 and TGS2620 are approximate linear functions of the stored time (Fig. 6) which can be expressed as follow:

$$y = 0.1330x+0.1619 \quad (R^2 = 0.9752), \text{ for TGS2600}$$

$$y = 0.1265x+0.1876 \quad (R^2 = 0.9856), \text{ for TGS2620}$$

where y is output voltage, x is stored time, R^2 is the correlation coefficient which shows good linear fittings. The slope of the equation for TGS2600 is larger than that of the equation for TGS2620, suggesting that sensor TGS2600 has higher sensitivity for the odor of beef. Both sensors can be used to determine the storage time of beef.

The output voltage of TGS2611 was almost unchanged for the first two days, but it suddenly rose when the storage time reached three days. The increase of output voltage of TGS2611 was larger than the others for beef storage time over three days, demonstrating that this sensor does not respond to fresh beef, but is sensitive to the spoiled beef. Therefore, it can be used to determine the beginning time of spoiling. TGS2610 is similar to TGS2611, but the former does not increase as much as the latter when the stored time is over three days. In general, sensors TGS2611, TGS2610 and TGS2602 can be sensitive to the spoiled beef although they do not respond to the fresh beef. They can be used to indicate spoiled beef.

There are many models of sensors made by different companies. It can be concluded that a suitable sensor matrix constructed by various sensors is sensitive to different gases. The present electronic noses generally available are composed of an integrated sensor matrix. Each electronic nose is basically designed for a specific purpose. So, electronic noses in the market have limited usage and are expensive as well. Based on our research results, a sensor matrix can be constructed of varied sensors, which is the developing direction of the research and development of the electronic nose. This method can make electronic noses cheaper and extend their usefulness.

4 Conclusions

Separate sensors were used to construct a sensor matrix and the relationship between the matrix and beef quality was investigated. The test results show that some sensors could not be used for detecting beef quality and the relationship between the output of some sensors and the storage time of beef is linear, but the decay of the beef could not be detected clearly. Some sensors have no reaction to the fresh beef but have intense reaction to the decayed beef. A sensor matrix assembled from sensors that react differently to beef freshness could improve the reliability and the sensitivity of detection.

Acknowledgement

This work was supported by the Key Project of Science and Technology Foundations of Jilin Province of China (Grant No. 20060217) and "Project 985" of Jilin University. The authors thank Professor Shou-qin Zhang of College of Biological and Agricultural Engineering, Jilin University, for his helpful discussion.

References

[1] National Bureau of Statistics of China, Review Report of the Social Economy Development of China during the "Tenth Five-Year Plan" Period, [2007-06], http://www.gov.cn/jrzg/2006-03/06/ content_219753_3.htm. (in Chinese)

[2] Lin X Y, He C Y, Gao Y Y, Lin X M, Liu Y H, Ruan R S. Nutritional and health of meat. *Meat Industry*, 2005, **1**, 42–45. (in Chinese)

[3] Wang L X, Li Q W, Liu J F, Yang X K. Application of risk analysis in management of agro-product quality safety. *Chinese Agricultural Science Bulletin*, 2006, **22**, 85–87. (in Chinese)

[4] National Standard of the People's Republic of China. Hygienic Standard for Beef, Mutton and Rabbit Meat, GB 2708-94. (in Chinese)

[5] Hu Q F. Testing technology of beef freshness degree. *Meat Hygiene*, 2005, **2**, 17–24. (in Chinese)

[6] Gao D Q, Wu S Y. Prospects for application of artificial olfactory systems to evaluation of internal quality of cigarettes. *Journal of Jiangsu University of Science and Technology*, 1997, **18**, 1–7. (in Chinese)

[7] Wu S Y, Zou X B. Progress in the application research of electronic nose for foods. *Journal of Jiangsu University of Science and Technology* (*Natural Science*), 2000, **21**, 13–17. (in Chinese)

[8] Pan Y F, Zhao J W, Zou X B, Liu M H. Using electronic nose qualifying apples based on ga-rbf network. *Journal of Agricultural Mechanization Research*, 2004, (3), 179–182. (in Chinese)

[9] Dutta R, Hines E L, Gardner J W, Kashwan K R, Bhuyan M. Tea quality prediction using a tin oxide-based electronic nose: An artificial intelligence approach. *Sensors and Actuators B*: *Chemical*, 2003, **94**, 228–237.

[10] Pan T H, Chen S, Zhao D A. Application of electronic nose technology in moldy foodstuff recognition. *Instrument Technique and Sensor*, 2005, (3), 51–52. (in Chinese)

[11] Brezmes J, Llobet E, Vilanova X, Saiz G, Correig X. Fruit

ripeness monitoring using an electronic nose. *Sensors and Actuators B*: *Chemical*, 2000, **69**, 223–229.

[12] Di Natale C, Macagnano A, Martinelli E, Paolesse R, D'Arcangelo G, Roscioni C, Finazzi-Agrò A, D'Amico A. Lung cancer identification by the analysis of breath by means of an array of non-selective gas sensors. *Biosensors and Bioelectronics*, 2003, **18**, 1209–1218.

[13] Teng J H, Yuan Z H, Wang L. Study degree of beef freshness with identification method based on gas sensitive. *Sensors Array Measurement and Control Technology*, 2002, **21**, 1–7. (in Chinese)

[14] Blixt Y, Borch E. Using an electronic nose for determining the spoilage of vacuum-packaged beef. *International Journal of Food Microbiology*, 1999, **46**, 123–134.